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An investigation into the speed and direction of motion of simple warm sector depressions

by

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Summary. For a limited class of depressions both the direction and the speed of motion are given with good accuracy by the 1000-500 mb. thermal wind. The mean value over an area centred on the depression gives better results than a "spot" value of the thermal wind through this layer. The results suggest that for this type of depression better forecast positions than could be expected by simple extrapolation or by the use of the tendency field might be obtained by using thermal wind as indicating speed as well as direction.

No other empirical rule could be formulated which gave equal success.

There is a suggestion that the relation between thermal wind and motion of depression is affected by thickness patterns showing marked "development" areas (Sutcliffe (1)) in the neighbourhood of the depression.

1. Introduction. A considerable amount has been written, by various authors, on the movement of depressions. Usually all types of depression have been considered together and results have usually been rather unsatisfactory.

Reasonable agreement was found by Hollis (2) using the 1000-500 mb. thermal wind, and by Austin (3) using the 700 mb. and 500 mb. winds, with regard to the direction of motion of depressions, angular deviations usually being within about 30 degrees. Hollis, however, found no correlation between the speed of the depression and the thermal wind speed.

It was therefore decided that better results might well be obtained by considering separately different types of depression - a good result over a narrow field probably being of more use to the forecaster than a somewhat unsatisfactory result over a much wider field.

It was also decided to measure the mean flow over an area centred on the depression rather than to use the usual geostrophic scale to measure the flow at a point over the centre. This was not only in view of the theoretical idea of the barotropic advection of a vortex in a general stream, but also to lessen the effect of the somewhat subjective details of chart drawing.

2. Selection of cases. Depressions in the six months 1/1/51 to 30/6/51 were considered. To avoid complication by orographic and diurnal effects, depressions over the Atlantic alone were considered, and depressions near the western extremity of the charts where the chart drawing might therefore be more erratic were also excluded.

/Depressions

Depressions which were occluded, and depressions with very complex or doubtful analyses (or whose position was in doubt due to lack of observations) were also omitted.

Very great care was taken to see that the upper air flow was typical of unoccluded warm sector depressions. Any cases with a closed cyclonic circulation at 500 mb. in association with the surface centre were excluded. The 1000-500 mb. thickness pattern had to be of conventional type also, cases being excluded if the thermal trough behind was unusually well marked or if there was marked difluence or confluence in the neighbourhood of the depression.

There were 16 satisfactory cases in the period considered. A further 18 cases were similarly obtained from the six-month period 1/7/50 - 31/12/50 and these were used to test the main results found from the original 16 cases.

3. Extraction of data. The motion of the depression was measured by its W to E and S to N components (in knots) over a 12-hour period (H to H + 12). Preliminary work indicated that the original drawing of the charts was somewhat erratic. Consequently all the surface charts, including the ones for several 6-hourly intervals before and after the 12-hour measured period, were completely redrawn, so as to satisfy fully all available observations and at the same time give a track for the depression which was as smooth as possible.

The upper flow over an area centred on the surface depression was estimated by measuring the difference in contour height (or thickness) at points a known distance due N and S, and again due E and W of the centre. This readily gave W to E and S to N speed components. The size of the area used was chosen in order to facilitate conversion into knots, a diameter of about 600 nautical miles being used. A scale was prepared for this purpose (Fig.1) which incorporates a correction for map distortion. The line AB is placed over the depression centre with the lines perpendicular to AB in the required direction (due N say) and such that the latitude figure on the scale conforms to the latitude immediately under it on the chart. The height (or thickness) is then read off on the line XY at the point appropriate to this latitude line on the scale. The height (or thickness) is similarly read in the opposite direction (due S say). For the 1:10^7 charts used, the scale was so drawn that the speed component in knots was given by multiplying the diametrical height difference by 4. It is a simple matter to prepare such a device for use with charts of any scale.

As well as the 1000, 700, 500 and 300 mb. winds and the 1000-500 mb. thermal wind (all of which were meaned over the two upper air charts at H + 3 and H + 9), measurements were made of the warm sector wind speed, the depression size and change of size, and the rate of filling or deepening. 6-hour isallobars were also drawn by gridding the surface charts.

4. Results. Correlation coefficients were calculated between the component velocities of the depressions and the wind components for the various levels and these are given in Table 1 below. There were 32 pairs of numbers (two components for each of the 16 cases) in the correlations. The correlation coefficient between the motion of the depression and the "spot" value of the 1000-500 mb. thermal wind using a geostrophic scale in the usual manner is also given.

TABLE 1

1000 mb. wind	.47	
700 mb. wind	.86	
500 mb. wind	.90	
300 mb. wind	.89	
Warm sector wind	.81	
1000-500 mb. thermal wind	.92	(.94 for the 18 test cases)
"Spot" value of 1000-500 mb. thermal	.80	

/The

The ratio of the depression speed (c) to the 1000-500 mb. thermal wind speed (V') varied between .66 and .98 with a mean value of .80. In the 18 test cases c/V' varied between .71 and 1.20 with a mean value of .97. The variations in c/V' were studied in relation to all the other parameters measured, and also in relation to tropopause height. No worthwhile correlation was evident. There was a slight tendency, however, for the smaller depressions to have a smaller value of c/V', (i.e. to move more slowly) and also for depressions whose size was decreasing to have a larger value of c/V' (i.e. to move quickly).

Previous writers have used angular deviation as a measure of the success of "steering" ideas, and values obtained in this investigation are given in Table 2 below:-

TABLE 2

Track of depression minus direction of:-	Mean	Standard Deviation	Mean ignoring signs
700 mb. wind	-5.5°	7.2°	7.6°
500 mb. wind	-2.9°	8.3°	6.5°
300 mb. wind	-4.1°	8.3°	7.4°
Warm sector wind	-6.1°	11.9°	10.2°
1000-500 mb. thermal	-0.6°	9.8°	6.3°

(the apparently smaller variability of the deviation from the 700 mb. direction is not thought to be significant, as this is based on only 15 cases. The case omitted is one in which lack of observations at 700 mb. made it impossible to give any reliable reading at this level - and it is by far the worst case of the 16 at the other levels, so that the 700 mb. level is doubtless favoured by its omission.)

It is interesting to compare the figures above with those for the angular deviation of the depression's motion from the direction of the isallobaric gradient. This gave a mean deviation of -2.3° (standard deviation 8.3) and, ignoring signs, a mean of 6.3.

It was found impossible to formulate any empirical rule to improve upon the thermal steering results by utilising any of the other parameters measured. It is particularly interesting that no success could be achieved in this way by using the 1000 mb. wind.

5. Errors. A rough check on the magnitude of errors involved in using thermal steering was thought to be worth while. Means and standard deviations were calculated for:-

(a) The difference between the 32 components for c and the corresponding components of $4V'/5$.

(b) The difference between the components for V' and the corresponding components found by subtracting the measured 1000 mb. components from the 500 mb. components.

(c) The difference between the components originally read off the charts for c, and those for c after redrawing the charts.

The values found were:-

	Mean	Standard deviation
a)	-0.5	1.5
b)	+0.5	2.4
c)	+2.4	5.4

/Now

Now a) is a measure of the reliability of using $4V/5$ as an estimate for c, whilst b) is to some extent a measure of the reliability of the charts. As this latter includes only errors of inconsistency in gridding and measurement, whereas there are also other errors (consistent drawing errors, observational errors, errors due to the geostrophic assumption) likely to worsen the reliability of our measurement of upper winds, b) is very probably an under estimate of the errors one might expect to find in the investigation by these methods of even a perfect steering law. Consequently the fact that a) is less than b) suggests that little improvement can be expected on the thermal steering result found, using present charting technique.

The fact that c) is more than twice as large as b) and about four times as large as a) suggests that considerably greater errors can exist in the placing of surface depressions on the Atlantic on the current surface chart than the errors involved in using thermal steering.

The standard deviations listed above are very small and the 18 further test cases gave somewhat higher values, but still gave a probable error of less than 5 kt. in using $4V/5$ as an estimate for c.

6. Conclusions.

(a) Non-occluded warm sector depressions over the Atlantic which have simple, conventional thermal structure, with no closed circulation at 500 mb. move in good agreement with steering by the 1000-500 mb. thermal wind.

(b) Better results are obtained by measuring the mean thermal wind over an area than by reading a "spot" value of the thermal wind at the depression centre. Such a mean value may readily be obtained by using the type of scale shown at Fig. 1.

(c) Simple warm sector depressions on the Atlantic move with the direction of, and slightly over 4/5 the speed of the 1000-500 mb. thermal, (meaned over an area) with a probable error of less than 5 kt. in speed and less than 10 degrees in direction.

(d) The surface pressure distribution in the vicinity of the depression seemed to have little effect so that the barotropic advection of a surface vortex in the surface stream does not seem to be a very helpful theoretical concept, in connection with these depressions.

(e) Although cases of marked "development" in the thermal pattern were excluded from this investigation, during the course of the investigation several cases were noted where there was marked difluence ahead of the surface centre. A cursory check suggested that in all such cases the speed of the depression was greater than would otherwise have been expected. The presence of marked development areas in the thermal pattern in the vicinity of the depression may well have some considerable effect on the motion of the depression, but this is a subject for further investigation and was not undertaken in the present work.

(f) Although the figures quoted throughout this investigation apply to measurements of the thermal wind simultaneous with the measured motion of the depression, and not to the reliability of thermal steering at any instant as a guide to the motion of a depression over the subsequent 24 hours, the technique of forecasting the pre-thickness charts is already sufficiently well developed for them to be used with reasonable confidence for forecasting the subsequent 24-hour motion of a depression if and when thermal steering is known to be the right principle to employ. The figures quoted in para. 7 above suggest that for the limited class of depressions considered, thermal steering by the 1000-500 mb. thermal wind might well give better results than extrapolation of the past track, or the use of isallobars, provided that the mean thermal is estimated over a substantial area centred on the depression.

REFERENCES

1. Sutcliffe, R.C. 1947. Q.J. 73, 317-318.
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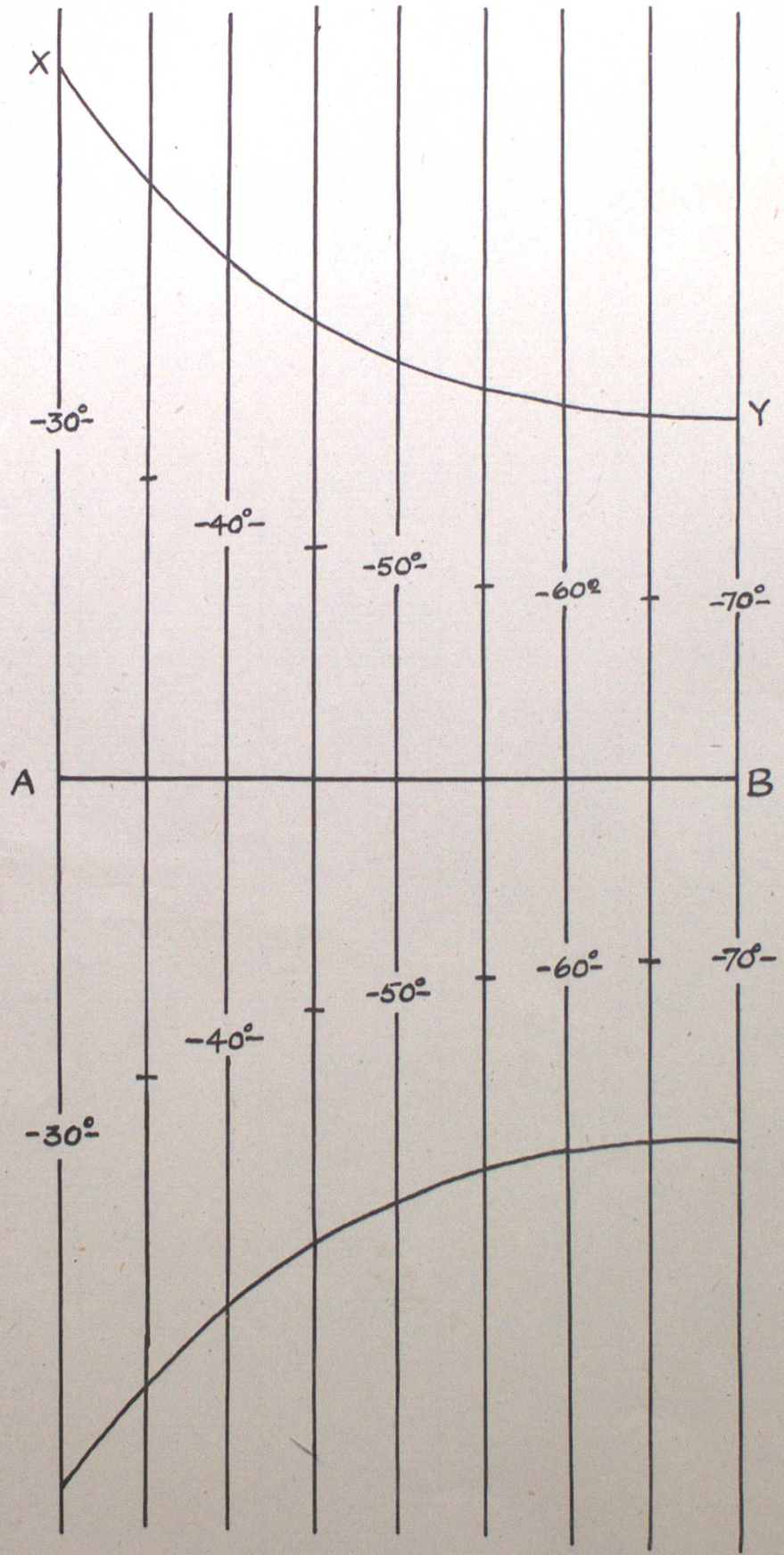

Fig. 1.

Scale for obtaining Mean Flow over an Area.